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# **Continued Use and Development of Existing Balloon-Borne Telescopes**

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CONTINUED USE AND DEVELOPMENT OF EXISTING BALLOON-BORNE TELESCOPES

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20. Abstract (Continued)

capability, and several proposals for other major changes were studied but were not implemented. The 50-inch system was used in all flights because its capability was better suited to the experiment objectives. Extensive work was done on the 24-inch system in the hope that it could be used in daytime experiments, but the target objective of tracking Mercury when it is high in the sky and close to the sun could not be achieved.

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### Summary

Work under this contract was concerned with two different balloon-borne telescope systems that had been constructed under previous contracts. The smaller 24-inch unit had been used extensively, first in lunar experiments and then in planetary studies, but the 50-inch unit had been finished only a short while before the current program began. Principal objective of this follow-on effort was to make flight use of the available telescopes, and to continually modify them to meet the needs of changing experiments. As it turned out the 50-inch system was used in all flights because the experiment objectives could be better achieved with the larger unit. Choosing the bigger telescope substantially increased the field effort because so much work is involved in preparing it for flight, in making the launch and recovery, and in refurbishing it for the next flight. Also, because the larger unit was new, there was need to devise an endless variety of special tools and fixtures that are needed for aligning and testing the system. Field recovery of the large optics was a new problem too because the 400-pound primary mirror cannot be handled by hand, as was the case with the optics in the smaller telescope.

Several proposed major changes in the telescope systems were

studied during the contract. Such work was fitted in with the continual evolution and improvement of the 50-inch system to meet flight requirements. Included in the special studies were the modifications required for tracking Mercury in the daytime using the 24-inch system, rerigging the 50-inch telescope for offset pointing, replacing the 24-inch optics with cooled optics, remounting of the secondary mirror in the 50-inch system to produce secondary stabilization by tilting the secondary mirror, and possible stabilization of the large telescope platform to operate in a non-tracking mode to study ground targets. Although these particular proposals were not implemented as changes to the telescope, a number of other changes were, and these enhanced the capability of the 50-inch system. Many of these were minor improvements that made more efficient the pre-flight checkout, the launch operations, or the recovery work, but some were larger projects. One was the construction of a special vehicle that simplified the field pick-up of the payload, and facilitated getting it back to the launch site. Another was the addition of a VOR unit for tracking the balloon's trajectory. Companion to this was the addition to the payload of a VHF command system and a VHF telemetering system, both of which added to the experiment capability because the facilities could be shared for experiment use. A very important new item added late in the program was a digital recorder that digitized and recorded the experiment data, and made both the analog and the digitized information available to the VHF telemetering system for transmission to the ground. Still another improvement concerned the development of better battery handling equipment for use by the Balloon Branch at Holloman.

When programming work, first priority was always given to the flight program and such modifications in the system as were needed to meet the experiment requirements. Responsibilities in the field work included the preparation of the telescope for flight use, making complete compatibility checkout with the experiment, attending to launch and recovery, performing postflight analysis, and repairing whatever

damage was incurred at impact. Other responsibilities in the field included the handling of problems associated with purchasing balloons, liquid gases, ballast, and other expendables, along with assisting experimenters in whatever way possible, particularly the trouble shooting of electronic equipment. No log was kept to show precisely how the total effort was divided among the various components of the program, but some notion can be had by noting that 31 per cent of the man days worked under the contract were spent in the field. Roughly an equal amount of time was devoted to preparing for work in the field, so the field aspect of the program was dominant.

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**Continued Use and Development of Existing  
Balloon-Borne Telescopes**

**1. INTRODUCTION**

Much of the effort under this contract was associated with the flight program and the continual modification of the telescopes to meet the needs of changing experiments. Coupled with the work of preparing the telescope for flight, procuring expendables, managing the launches, assisting in recovery, doing postflight analysis, and repairing the system for the next flight, there was a continual development of new devices and techniques that made one or another of these field operations easier or more efficient. All of the flights that were requested were accomplished, and all of the improvements that were made to the telescope systems are now part of those systems. Data gathering and data handling was done by AFGL experimenters so the preservation of the scientific results has been their responsibility.

During the life of the contract several studies were made of proposed major modifications to the telescopes that would allow them to be operated in different ways. Certain of these were not implemented so the results do not exist in the form of improvements to

the telescope systems. These are separately recorded under appropriate headings in the remainder of the report. Also included is a section that describes more fully some of the principal modifications and improvements that were incorporated to extend system capability. Minor gadgets and techniques that were generated from time to time are not mentioned.

## 2. STRATOCHAMBER TESTS

When the 24-inch telescope system was used in lunar and planetary experiments a photographic record was always made of the area toward which the optics were directed, primarily to be certain that the programmed target was studied. These photographs were also used to evaluate the precision of pointing, and they gave information about focus. Temperatures of both the primary and the secondary mirror were recorded for use in reducing experiment data, so these were available for calculating a suitable preflight offset in the focal plane to compensate for the temperature changes that occur when the telescope is carried aloft. Changes in focus due to temperature are greater for the 50-inch system than for the 24-inch because the gain of the secondary is  $6 \frac{2}{3}$  as opposed to  $3 \frac{1}{3}$  for the smaller optics. In order to evaluate the problem before starting the flight program with the 50-inch system, arrangements were made to put both telescopes through chamber testing at Holloman. This provided opportunity to actually measure the shift in the focal plane under simulated flight conditions, and to compare measured values with those predicted from the measured temperature changes.

Before work in the chamber could begin it was necessary to solve two problems of considerable size, namely the manufacture of hardware for mounting the large optics in the confined chamber space, and the fabrication of suitable instrumentation for measuring the location of the focal plane during the test. The optical arrangement used for monitoring the position of the focal plane utilized a light source and

beam splitter located behind the primary mirror, and two penta prisms suitably positioned in front of the mirror. Such an arrangement produces two small light beams coming back through the system that intersect at the focal plane. One of the pressurized star tracker assemblies was used for inspecting the light beams near the focus. It was carried on a traveling mechanism that allowed an operator outside the chamber to move it back and forth along the optical axis by known amounts. Provision was made for scanning the face of the photomultiplier and for observing the output waveform. Two separate pulses appear at locations where the light beams clearly do not intersect, and a single pulse is seen where the spots coincide. Width of the pulse is narrowed at crossover, but peaking of the signal gave the best indication of exact spot superposition. Accuracy of establishing the crossover point was about 0.02". Troubles from 60 Hz modulation of the light intensity, and from vibrations coming from the refrigeration system, produced most of the measurement troubles.

Two different chamber tests were made on the 24-inch system, one using beryllium rods for spacing the secondary with respect to the primary, and the other using Invar-60 rods. A great many temperature sensors were used throughout the chamber and on the telescope system, particularly on the primary mirror, the secondary mirror, and the rods. Temperatures on the various chamber surfaces differed appreciably so the environment provided in the test was not completely representative of what would be experienced in a typical flight even though the programming of the chamber had attempted to duplicate the time-altitude and time-temperature profiles that are typical of a balloon flight at Holloman. Not only were the temperatures on the walls, the ceiling, the floor, and the door different from each other, but they were appreciably different from programmed values due to the fact that the chamber was incapable of cooling the system as rapidly as the flight profile called for. However, the optics were submitted to a flight-type environment that gave opportunity to study their behavior under such conditions.

From the results obtained in the tests of the 24-inch system it was evident that Invar-60 rods were more suitable than beryllium, so the 50-inch system was tested only with Invar-60 rods. The time, and considerable expense, that would have been involved in repeating the test with beryllium rods did not appear to be justified. Procedures in making the chamber test with the big optics were essentially the same as those used with the smaller system, but there was much more difficulty in suitably mounting the large optics in the confined chamber space. Chamber experience with the smaller optics was useful in getting reasonably representative temperature and altitude profiles for the larger optics, given the limited capability of the chamber system. Also, some of the cold spots caused by forced circulation of air within the chamber were avoided in the later tests. Troubles from vibration were somewhat greater in the setup of the large optics, but the accuracy of the results is believed to be about the same as before.

Results from the chamber testing of both optical systems were studied and analyzed. Measured temperatures were completely different for the three critical parts of the optical system, namely the primary, the secondary, and the rods. Rod temperatures were always nearly the same as the ambient temperature of the air at the location of the rods. Mirror temperatures, both primary and secondary in both systems, were characterized by fairly rapid rates of decrease at low altitude where the air is dense and convection is good, and progressively slower rates of decrease at higher altitudes where the air density and convection falls off. After reaching ceiling altitude the temperatures of all mirrors dropped at nearly constant rates, but the rates were very different for the different mirrors. Behavior in the chamber can be approximated by giving for each mirror the drop in temperature during ascent, and the rate of decrease in degrees per hour after reaching ceiling altitude. For the 24-inch system the drop in temperature during ascent for the primary averaged 23°C in the two tests, and the rate of decrease at ceiling altitude averaged

3.6°C per hour. Corresponding results for the secondary were a drop of 55°C followed by a steady decline at 4.8°C per hour. For the 50-inch optics, the drop in temperature during ascent for the primary was 10°C, and the subsequent constant rate of decrease was 1.8°C per hour. Temperature drop during ascent for the secondary was 23°C, followed by a linear decline at 4.2°C per hour. Although the measured temperature changes were different from those experienced in flight, they were valid inputs for predicting the shift in the position of the focal plane.

Before a comparison could be made between predicted and measured shifts in the position of the focal plane it was necessary to make a careful analysis of the optical system. Factors that cause the focal plane to move are changes in rod length, which alters the spacing between the primary and the secondary, and changes in the curvature of the mirrors. An equation was derived that expresses the magnitude of the shift of the focal plane in terms of the temperature change of the primary mirror, the temperature change of the secondary mirror, and the temperature change of the rods. In making this derivation it was assumed that the mirrors were homogeneous and at a uniform temperature, and that all dimensions and radii of curvature change linearly with temperature. It was realized that a bimetallic effect can also contribute to the change in shape because all mirrors are Kanigen coated, and the coefficient of expansion for Kanigen is different from that for beryllium. In manufacturing the 50-inch system, care was taken to polish the back surface of both mirrors, which were flat, so the thickness of Kanigen on both the front and the back of these mirrors is about 0.003 inches. This precaution could not be exercised in the manufacture of the 24-inch system because the back surfaces of those mirrors are not perfectly flat.

Shift of the focal plane is given by the equation

$$\Delta b = \frac{G^2}{2} R_p \rho_p \Delta T_p - (G^2 + 1) D \rho_D \Delta T_D - \frac{(G-1)^2}{2} R_s \rho_s \Delta T_s$$

where

$b$  = distance in inches from primary apex to focal plane

$\Delta b$  = change in  $b$

$R_p$  = radius of curvature of primary in inches

$R_s$  = radius of curvature of secondary in inches

$D$  = spacing between primary and secondary in inches

$\rho_p$  = coefficient of thermal expansion of primary in  
inches/inch/ $^{\circ}\text{C}$

$\rho_s$  = coefficient of thermal expansion of secondary in  
inches/inch/ $^{\circ}\text{C}$

$\rho_D$  = coefficient of thermal expansion of rods in inches/  
inch/ $^{\circ}\text{C}$

$G$  = gain of secondary

$\Delta T_p$  = change in primary temperature in  $^{\circ}\text{C}$

$\Delta T_s$  = change in secondary temperature in  $^{\circ}\text{C}$

$\Delta T_D$  = change in rod temperature in  $^{\circ}\text{C}$

An expression in terms of time rates of change can be had by replacing the increments  $\Delta b$ ,  $\Delta T_p$ ,  $\Delta T_D$ , and  $\Delta T_s$  by the time rates  $db/dt$ ,  $dT_p/dt$ ,  $dT_s/dt$  and  $dT_D/dt$ . Numerical values for temperature coefficients, and for mirror constants, are

$\rho = 11.5 \times 10^{-6}$  inches/inch/ $^{\circ}\text{C}$  for Kanigen

$\rho = 1.6 \times 10^{-6}$  inches/inch/ $^{\circ}\text{C}$  for Invar-60

$R_p = 144$  inches for 24-inch optics

$R_s = 56.7$  inches for 24-inch optics

$D = 52.15$  inches for 24-inch optics

$G = 3 \frac{1}{3}$  for 24-inch optics

$R_p = 150$  inches for 50-inch optics

$R_s = 30.69$  inches for 50-inch optics

$D = 61.96$  inches for 50-inch optics

$G = 6 \frac{2}{3}$  for 50-inch optics

Since two different kinds of rods were used in the two chamber tests on the 24-inch system, a different expression for  $\Delta b$  applies in the two cases. For beryllium rods, where  $\rho_p = \rho_s = \rho_D = 11.5 \times 10^{-6}$ , the

equation becomes

$$\Delta b = 0.009216 (\Delta T_p - 0.7896 \Delta T_D - 0.1929 \Delta T_s) .$$

For Invar-60 rods, where  $\rho_D = 1.6 \times 10^{-6}$ , the equation is

$$\Delta b = 0.009216 (\Delta T_p - 0.1098 \Delta T_D - 0.1929 \Delta T_s) .$$

Chamber tests with the 50-inch system were made only with Invar-60 rods, so the applicable expression for  $\Delta b$  is

$$\Delta b = 0.038400 (\Delta T_p - 0.1173 \Delta T_D - 0.1478 \Delta T_s) .$$

Agreement between predicted and measured results was good. Measured and predicted rates of change of the position of the focal plane when the system was at ceiling altitude did not differ by more than the error in experimental measurement, but the shifts associated with the initial plunges in temperature differed by double this amount in the case of the 50-inch test, and by almost four times the experimental error in the other tests. Such agreement was considered satisfactory considering the disturbing environment of the chamber, which probably did lead to temperature gradients in the primary mirror because of the fans that forced circulation in the chamber.

The conclusion reached from the study was that ascent time should be kept as low as possible in using the 50-inch system because of the sizable shift in the position of the focal plane associated with the drop in temperature prior to reaching ceiling. It was also concluded that a preflight offset can be made which will place the focal plane at the desired position near the mid-point of the data-taking interval, with the result that the system will be in acceptably good focus while data is being collected. Inputs for predicting the appropriate offset requires the continued accumulation of temperature measurements during flight for the primary mirror, the secondary mirror, and the rods. Also, temperatures of all optical components must be recorded at the time the system is initially focused. Temperature factors were considered throughout the flight program, and always a preflight offset was made based on the available input data.

A look at the three numerical expressions for  $\Delta b$  is revealing in that the rods and the secondary tend to move the focal plane toward

the sandwich as the temperature falls, and the primary tends to move it away. When beryllium rods are used the contribution from the rods dominates because the rods change temperature much more than does the primary mirror. It would be prohibitive to use beryllium rods in the 50-inch system because the change in temperature of the primary mirror is only 1/5 that of the rods. When Invar-60 rods are used it is clear that the relative importance of the three contributing factors is about the same for both optical systems, but the contribution made by the primary mirror is more than four times larger for the big optics because  $G^2$  for that system is four times larger.

The objective in doing the work in the chamber was to establish a basis for making preflight offsets in the location of the focal plane that would compensate for shifts associated with changes in temperature of the optical components during flight. The alternative is to incorporate a facility for monitoring the location of the focal plane during flight, and for commanding changes from the ground. While this procedure has advantages, it would have added considerable complication to the system so no attempt was ever made to incorporate such features.

### 3. DAYTIME TRACKING

When work under the contract began the new spectrometer being built by AFGL was not ready so time was available for investigating the problems associated with modifying the 24-inch system for tracking planets in the daytime. Reason for this attempted modification related to a desire to make observations on the planet Mercury. For the experiments contemplated it was necessary to have reasonably large elevation angles to avoid long air paths, and this meant solving the problems of finding and tracking a dim target that is fairly close to the sun. The magnitude of Mercury fluctuates from roughly +3 to -2, and elongations vary from 0 to about  $28^\circ$ . Unfortunately the favorable magnitude values appear only when the elongations are small, and



vice versa. Luminance of the sky in the daytime is very high at positions near the sun so the background problem is enormous, but at ceiling altitude the situation is less prohibitive. After reviewing references pertaining to sky luminance, and talking with those who had successfully tracked the planet Venus in the daytime when its elongation was near  $45^{\circ}$ , it was concluded that for successful checkout at ground level the system must be capable of finding and tracking a target of +1 magnitude when the sky luminance is 3 lamberts. Expected values of sky luminance at ceiling altitude are roughly twenty times lower, or about 0.15 lamberts.

A study was made to determine how the system could be modified for daytime tracking without changing the nighttime tracking arrangement. General features of the system were to be retained, existing wiring was to be kept but more could be added, new circuit boards could be built, photomultiplier tubes could be changed, and additional equipment units could be installed. Important limitations were imposed by physical dimensions of the rack, namely height, because limited height prevented incorporating a sun shield of the type that Strong and associates found absolutely necessary in their work with Venus. They were able to track Venus in the daytime only if direct sunlight was prevented from striking the inner wall of the tube that shielded the tracker, otherwise daytime tracking at ground level could not be done because of troubles arising from light scattered by dust particles. The essential protection was achieved by a knife-edge sunshade made by cutting a cylinder at an angle with respect to its axis that was smaller than the angle between the target and the sun. Such a device is convenient when the diameter of the shade is small and the angle to the sun is  $30^{\circ}$  to  $45^{\circ}$ , but it is another matter when the lens diameter is 24 inches and the angle to the sun is as small as  $15^{\circ}$ . A shade at least 12 feet long on the side toward the sun would be needed, and this simply could not be accommodated. But it had been emphasized that this particular shielding had proved absolutely essential, so it appeared from the outset that Mercury

could not be tracked during the daytime on the ground. However, the project was pursued because the twentyfold advantage at ceiling altitude gave hope that the experiment could be conducted if an adequate ground checkout could be simulated.

To understand the proposed modifications it must be kept in mind that acquiring targets in nighttime experiments involves a sequence of operations. First the azimuth and elevation angles of the telescope system are set at values prescribed by an onboard programmer, using a gyrocompass and a pendulum as references. Next a raster-type search is made of an area several degrees square and the brightest target is acquired by a star tracker associated with optics of 7-inch focal length, the selection of the brightest target in the field being determined by setting a threshold that excludes dimmer ones. The telescope is then stabilized using error signals developed by the aforementioned star tracker, and a second search is initiated by causing the target to be rastered across the face of the photomultiplier tube in the tracker. Searching of this type continues until the star tracker associated with the main optics, of 180° focal length, locks on the target. After this the telescope is controlled by error signals from the second star tracker. Visible flux only is used for tracking, with the infrared flux being reflected into the experiment spectrometer.

It was evident from the beginning that the nighttime sequence could not be used in the daytime experiment because the ratio of signal to noise-in-the-background for the short focal length system would be too small. A careful analysis produces an expression for signal as a ratio to noise-in-the-background illumination equal to

$$S/N = (10^{-2} \times 2.51^{-M} \times D \times F/d) (t/B)^{1/2}$$

In this expression M is the magnitude of the target, D is the diameter of the optics in inches, F is the focal length of the optics in inches, B is the luminance of the sky in lamberts, d is the IEPD for the photomultiplier in inches, and t is the dwell time in seconds. The constant  $10^{-2}$  is approximate since it depends on assuming reasonable values for several quantities associated with the optics

and the photomultiplier tube, including the unit efficiency of the optics, the counting efficiency of the multiplier, the quantum efficiency of the cathode for light from the target, the quantum efficiency of the cathode for light from background flux, the  $\mu\text{A/lumen}$  response from the photocathode, and the factor by which noise is increased in the multiplier section. Tubes can be selected for best quantum efficiency, but this was not done because the improvement in S/N increases only with the square root of that efficiency. However, a switch was made from tubes with IEPS of 0.1 inch to tubes with IEPS of 0.014 inches, a change that increased S/N by a factor of 7. Special tubes with smaller IEPS were not considered, partly because of procurement time and partly because their off-axis performance is degraded because of focus problems. An estimate for S/N, if the small optics were to be used for acquiring the target, can be had by using the equation for S/N with  $M = 1$ ,  $d = 0.014$ ,  $D = 2$ , and  $F = 7$ . The result is  $S/N = 2.2 t^{1/2}$ . For the 24-inch optics, where  $D = 24$  and  $F = 180$ , the result is  $S/N = 690 t^{1/2}$ . If acquisition is to be made in a reasonable time it appeared necessary to keep dwell time down to about  $25 \times 10^{-6}$  seconds. This makes S/N for the small optics only 0.01, so the nighttime means of acquiring the target would be useless. But S/N for the same dwell time is 3.5 for the large optics, so daytime tracking would be possible provided the predicted troubles from light scattered by dust particles does not dominate.

Acquisition during the daytime must be accomplished by using the sun. In the proposed plan, coarse orientation of the telescope in azimuth and elevation would be achieved by means of an on-board program as was done in the nighttime version. A sun tracker whose optical axis could be offset in a programmed way from that of the main optics would be carried as a part of the system, and the goal of the initial search would be to acquire the sun and stabilize the system with signals coming from the sun tracker. Fine searching could then be done by causing the image of the sun to be moved across the face of the photomultiplier tube in raster fashion until Mercury was captured by a tracker asso-

ciated with the main optics, then the target would be tracked in the usual way with essentially the same precision that has been achieved in nighttime experiments.

A good many changes had to be made to implement such a plan. First of all a sun tracker had to be built that could be offset in elevation and cross elevation by known and precise amounts, and circuitry had to be provided for on-board programming of the offsets. A baffle system was added to the main optics, and a trap door was installed to protect the photomultiplier tubes and the AFGL spectrometer from direct exposure to the sun. The protective door was interlocked in a way that would keep it closed at all times except when the telescope was being guided by the sun tracker. The star tracker associated with the main optics was completely changed. A tube with IEPD of 0.014" was substituted for the one normally used, a completely different system of signal processing was incorporated, sweep frequencies were changed, different electrical filters were installed, and provision was made for setting an adjustable threshold that would allow clipping the signals coming from background flux. A good many wiring changes of course had to be made, but these were all overlaid on the existing wiring in order to preserve the nighttime version of the system.

Mounting of the sun tracker on the sandwich was so arranged that its cross-elevation axis coincided with that of the sandwich, but its elevation axis could not be parallel to the elevation axis of the sandwich because of the offset. Since error signals generated by the sun tracker are related to elevation and cross elevation as measured with respect to the sun they are not the ones needed to steer the sandwich that carries the main optics. Cross coupling and gain changes are involved that depend on the offsets. Relationships for the needed coordinate transformation were worked out, and a computer program was generated for producing the offset angles that must be fed into the sun tracker system. When all of the needed equipment was built up and installed a determined attempt was made to make the system acquire and

track Mercury in the daytime on the ground, but this effort was unsuccessful. Luminance of the sky and troubles from dust particles were too severe. A different ground test was then undertaken to demonstrate that daytime tracking was possible with this particular system. At the time the test was wanted, Jupiter was about  $90^{\circ}$  from the sun and the moon happened to be near enough to that planet so that it could be used instead of the sun as a means of achieving acquisition. Such an arrangement permitted a clean demonstration that the system could indeed acquire and track Jupiter in the daytime, but the target was at least two magnitudes brighter than Mercury would be, and the elongation was considerably greater than for Mercury. Signal to noise ratio achieved in this work indicated that troubles were coming from sources other than the sky background, and that this interference would have to be eliminated before the hoped for goal of acquiring and tracking Mercury in a daytime experiment could be checked out at ground level.

By the time this result had been obtained there was need to get on with the flight program of the 50-inch system because the new AFGL spectrometer was nearing completion. Consequently the work on the daytime tracking project was stopped in order that chamber tests could be made on both telescope systems prior to making a flight with the larger one. Additional work was done on the project later in the contract, and the 24-inch system was kept in the daytime-tracking configuration for another year, but no attempt was ever made to use the system in a daytime experiment, primarily because the 50-inch system was always a more attractive way of accomplishing the desired experiment objectives. Later in the program the daytime features were removed because it was then desired to rerig that platform with cooled optics of 10-inch or 12-inch size.

#### 4. OFFSET POINTING OF 50-INCH SYSTEM

Work was done on the problems associated with modifying the 50-inch telescope system for offset pointing. Incorporation of a programmable and controllable offset between the acquisition optics and the main optics would allow two modes of operating the telescope that experimenters thought might be used in the flight program. In the one mode the main optics would acquire and track very dim targets when led to those targets by having the offset tracker lock on nearby guide stars. In the second mode guidance would be entirely by means of the offset tracker, and the main telescope would be directed toward invisible targets. Modifications involved in making mode 1 possible are somewhat less severe than for mode 2. Reason for wanting the mode 1 modification is that the tracker associated with the main optics can track targets about 5 magnitudes less bright than can be acquired by the acquisition optics. Incorporating an offset feature would allow the acquisition optics to acquire and track a reasonably bright guide star, and thus hold the telescope steady with the main optics directed toward the precise area where the dim target is located. A search of a small area in this vicinity would allow the desired dim target to be found and tracked by the tracker associated with the main optics.

The planned method for incorporating the offset feature was to make an integral assembly by coupling the lens for a 5-inch Celestron telescope to one of the pressurized tracker units that have been used in both telescope systems. This assembly would be narrow enough in the section between the lens and the photomultiplier to have it pass through the hole in the sandwich that is normally used in mounting the acquisition optics. A gimbal was to be placed on the front of the sandwich, and the mechanics for offsetting the assembly in polar-coordinate fashion was to be located on the rear of the sandwich. Although a good amount of precise mechanical mechanism is involved, there is sufficient space available for incorporating such an

arrangement. Numerous circuit changes are required, but these are all compatible with the existing circuitry so could be readily incorporated. A significant change, however, concerns the field of view of the offset tracker, which is also the acquisition optics. Field of view in the present acquisition system is about  $3^\circ$ , but this would be reduced to  $0.6^\circ$  if the proposed Celestron lens was substituted. The fivefold reduction in field of view would require the initial search to be changed, and this would lengthen the time for initial acquisition. But using the Celestron lens, of approximately 50-inch focal length, in the acquisition system would have a distinct advantage in that the accuracy of pointing with the offset tracker would be about five times better than is the case with existing acquisition optics. This would be helpful in acquiring a dim target as proposed in mode 1, and it would be especially advantageous if the system were to be operated in mode 2 because the ultimate pointing in mode 2 is done with the offset tracker.

The real limitation in the accuracy of pointing in mode 2 comes from the pendulous swinging of the payload as it is suspended from the balloon. Amplitude of the pendulous motion occasionally reaches  $0.5^\circ$ , although it is usually a few times smaller. The desired pointing accuracy in mode 2, when the target itself isn't being tracked, was a modest one arc minute, and this was wanted with offsets to the guide star up to  $10^\circ$ . With a  $10^\circ$  offset, the optical axis of the main telescope can move more than 5 arc minutes if the cross-elevation axis is tipped by  $0.5^\circ$  due to package swinging. Simple offset pointing therefore is not satisfactory for mode 2 even if the offset tracker points exactly toward the guide star. Another requirement was that the offset tracker acquire and track stars to +4 magnitude, but this did not constitute a problem because a 5-inch diameter lens would intercept enough flux to operate the star tracker.

The planned means of dealing with the swinging problem was to utilize two guide stars and two offset trackers, one mounted in the lower right-hand corner of the sandwich where the acquisition optics

are presently located, and another in the lower left-hand corner where sufficient space is available for mounting a second unit. Signals from one tracker would guide the sandwich, and signals from the second would be used to measure the tipping of the cross-elevation axis. Offset between the main optics and the sandwich-guiding tracker could then be corrected on a dynamic basis in a way that would compensate for the package swinging. Problems of cross coupling such as were encountered in the daytime tracker were considered, but circuitry for transforming coordinates was not planned because the cross coupling is small with  $10^\circ$  offsets. Some of the gearing required for fabricating the offset mechanisms was acquired, but the telescope system was not reworked for offset pointing because the flight program was continually involved with targets that could be tracked directly. However, a first step toward implementing the plan for mode 2 was made during the refurbishing that followed the flight made on 30 June 1974. At that time it was convenient to send the heavy sandwich to the machine shop at Holloman and have a second hole bored through the sandwich in the lower left-hand corner where the second offset tracker was to be located. Also, the computer program generated for use in the daytime tracking exercises was reworked for the two-star plan, so this software was available if the flight program had required implementing the plan.

#### 5. COOLED OPTICS POSSIBILITY

One of the possibilities given consideration about midway through the contract was to replace the 24-inch optics in that telescope system with cooled optics of smaller size, possibly 10 inches or 12 inches. At that point in time the interest in the daytime tracking option had diminished so work was done toward rerigging the system in a different way. Cooled optics were to be provided by AFGL so the contract work involved cooperatively studying the manner in which the proposed experiment could be accomplished. It appeared that pointing of the



type that is presently done, which uses visible light coming through the main optics, would be difficult in the cooled-optics arrangement. Advantages of the present arrangement are that the focal length of the main optics is long, and there is no boresighting problem. Focal length of the cooled optics was not expected to be long, so that advantage was lost. It therefore seemed better to do fine pointing with a separate tracker that would have to be accurately boresighted with the cooled optics. Adequate space would be available for a separate tracker because of the smaller size of the proposed cooled optics. Circuitry for the separate tracker would be essentially the same as in the existing 24-inch system. If implemented, the modification would have involved removing the tracker now used with the main optics and associating it with auxiliary optics, probably a lens for a 5-inch Celestron telescope. Pointing with such an arrangement would be poorer than is presently possible with the 24-inch system because the focal length of the fine-tracking optics would be reduced from 180 inches to 50 inches, but the expected precision of pointing with this arrangement was believed to be satisfactory for the cooled optics experiments. However, the cooled optics experiment was not produced, so the additional tracker mentioned above was not installed. At the present time the 24-inch telescope system is rigged in its original configuration, which has an acquisition tracker that utilizes 7-inch focal length optics, and fine tracking is done using the main optics of 180-inch focal length.

#### 6. REMOUNTING OF SECONDARY

Secondary mirrors in both the 24-inch and the 50-inch telescope systems are held in position by means of six rods that are fixed with respect to the primary mirror. This arrangement has been advantageous because it allows the sandwich to move in the cross-elevation direction by as much as  $\pm 15^\circ$  without having the structure at the secondary encounter the sides of the rack. Also, the six-leg structure has

proved to be a very stable way of holding the secondary where it should be. The arrangement is lightweight, and it is easy to remove during recovery in the field. But light reflected from the round rods has been troublesome in some of the experimentation, so the mounting of the secondary was reconsidered. The conclusion was that the problem of reflected light from the rods could only be solved by replacing the existing mounting with a more conventional one.

Reducing the light reflected from the rods was only part of the goal in remounting the secondary in the 50-inch system. In that system, it was also desired to perform secondary stabilization by servo control of the secondary mirror. Secondary stabilization is now achieved by guiding a small gimbaled mirror on the back of the sandwich. This works well but does introduce additional reflecting surfaces that would be eliminated by the proposed change.

A serious difficulty in remounting the secondary mirror in a conventional way arises because there is not enough room within the rack to accommodate a large ring, or a tube, from which the secondary can be held by a spider arrangement. Any structure at the location of the secondary that is as big in diameter as the primary, or larger, would drastically restrict motion about the cross-elevation axis because of the limited width of the rack. A further problem is involved with the rack height, which would have to be increased to allow the large diameter to clear the top of the rack as the optical system moves from its vertical position at stow to elevation angles suitable for data taking. The problem of increasing the rack height can be solved by inserting an extender section on either side of the rack, but this modification would require incorporating some objectionable outriggers to compensate for the loss of diagonal supports that are presently inside the rack at the top, and are needed for stiffening the structure. A large reduction in movement about the cross-elevation axis would require a change in the method of searching for targets. Reason is that gyrocompass headings can be in error by as much as one or two degrees, so the azimuth search must

be large enough to cover this uncertainty as well as the field to be searched. This problem can be handled by introducing a search mode into the gyrocompass servo such that the payload would be moved back and forth a few degrees in azimuth during search. Although this can be done, it is not a particularly desirable way of making the azimuth search because the massive payload is suspended from the balloon through a long and torsionally weak linkage.

Because the secondary is located about five feet from the elevation axis, the addition of an appreciable amount of weight there introduces a large unbalance about the elevation axis that would require an almost intolerable amount of counterweight below the sandwich, or would necessitate repositioning the elevation axis appreciably toward the secondary location. The latter possibility was looked at carefully but was judged to be an unsuitable choice. A design attempt was therefore made to circumvent the weight problem by supporting the secondary on a lightweight spider that is stiff in the plane of the spider. Positioning of the spider in the plane normal to the optical axis would be accomplished by a typical eight-leg arrangement, with two legs attached at each corner of the sandwich. However, the spider would not be rigidly fastened to the top ends of the support rods, but would only be positioned by them in the plane of the spider. Spacing of the spider from the primary would be done by four small diameter rods attached to the edge of the primary mirror. Adoption of a lightweight design would still introduce appreciable unbalance in the system about the elevation axis, but balance could be restored by adding a manageable amount of weight behind the sandwich, thus avoiding the need for repositioning the elevation axis. Extension of the rack height would be necessary with the lightweight arrangement, as it would be with any arrangement that is physically large at the secondary location. Troublesome questions about such a plan arise because the secondary might shift laterally with respect to the primary because each is separately located with respect to the sandwich. In the presently used arrangement the

secondary is positioned with respect to the primary, and the two move together if there is slippage with respect to the sandwich when the temperature plunges. A further objection is that some small distorting forces are applied to the primary mirror that are not present in the existing arrangement. But in spite of the difficulties it was expected that a lightweight arrangement of the type suggested would be tried if the problem of reflected light from the six-rod structure became intolerable.

Mounting the secondary in the 50-inch system so that it can be servoed in two directions was looked at carefully. A gimbaled design was avoided because of problems with obscuration and scattered light. Instead the plan was to hold the secondary on a mount located behind the secondary itself, which meant that tilting the mirror would cause its apex to be moved laterally as well. A tilt of the secondary of about 600 arc seconds is required to accomplish the raster that is currently used, which is of 100 arc second size. Lateral movement of the apex associated with this amount of tilt can be held to approximately 0.003" by keeping the pivot as close as possible to the back of the secondary. This amount of lateral motion is acceptable.

Problems associated with controlling the secondary mirror with the needed precision could have been readily handled, even with the lightweight mount. But no remounting scheme was implemented, with or without secondary stabilization, because the existing arrangement continued to satisfy the experiment program, and there was no desire to exchange a convenient stable system for one that has questionable features. The only step actually taken toward implementing the changes mentioned was to have a 36-speed synchro installed in the gyrocompass. This change from the single speed synchro would allow better control as the payload is turned about the azimuth axis during initial searching.

## 7. NEW BATTERY HANDLING EQUIPMENT

Preparation of batteries for the telescope flights has always been done by Holloman personnel using charging equipment that is available there. Many batteries are required for a telescope flight, and this has meant combining cells that have been in service for different lengths of time. Since the initial charge as well as the capacity to hold charge is different for each cell, the preparation should be done on a cell-by-cell basis. Also it should be possible to discharge cells that have been fully charged to make sure those of older vintage are still worthy. Equipment is not available at HAFB for handling cells individually. Charging is done by connecting many cells in series, and the process is continued until the total voltage for the series arrangement corresponds to 2 volts per cell, then an automatic turn-off is actuated. Such a procedure is dangerous unless the voltage across individual cells is frequently and faithfully measured because some cells can be overcharged, thus making them unfit for flight use. No equipment is available at Holloman for properly discharging batteries. When batteries have been discharged they have been connected in series, and the voltage of the various cells has been periodically measured. The procedure is poor because a slip in the monitoring can lead to reverse charging of one or more cells, and this will also make them unfit for flight use.

It was clearly demonstrated during the preparation of batteries for the flight made 2 June 1975 that battery preparation at HAFB is a critical problem, and that personnel at the Balloon Branch there should not be counted on to faithfully perform the tedious preparations that are necessary with the existing equipment. Although the battery handling problem is separate from the problems normally involved in readying the telescope system for flight, it was decided that new battery-handling equipment should be designed that would allow batteries at Holloman to be either charged or discharged on a

cell-by-cell basis. What is needed is specialized equipment that will charge or discharge any of the four types of batteries that are used in balloon flights at HAFB without requiring the operator to make any decisions or do any monitoring. Once a battery of any of the four types is connected, the rest should be handled by the equipment. Charge or discharge current should be constant at the correct value, turn-off should be automatic, and on-time should be individually recorded for each cell. Initially it appeared that equipment with these features could be produced without too much difficulty, but on closer study it proved to be a sizable effort.

The problems involved in designing a system were worked on whenever time permitted, and two model devices were worked out, one for discharging and one for charging. The circuitry for each unit has been so arranged that the operator makes no decisions whatever, and it is impossible for him to use the wrong charge or discharge rate. A separate connecting head is used for each type of battery, with the hole spacing and hole size such that only the correct battery can be inserted. When any of the four heads is inserted into the charge or discharge unit the charge or discharge process will be continued at the correct constant rate until the proper end point is reached and the operation is automatically terminated. No time keeping is needed because the amount of charge, or discharge, is recorded on a separate counter for each cell. Use of this type of equipment will accomplish the desired goal in that cells will not be charged beyond 2.00 volts, reverse charging will never be done, discharge beyond the 1.0 volt end point will not occur, and it will be possible to occasionally measure the capacity of batteries by discharging them after they have been fully charged. It will also be easy to keep records on individual batteries and individual cells by recording the life history of each as measured by the numbers available from the counters. Most important, however, is the fact that the preparations can be made without constant supervision, and batteries with various service records can be safely combined for

flights of the telescope. Worries about weak or damaged cells that can shorten the data-taking period, or possibly cause a flight failure, should no longer be a problem. Models of the charge and discharge units, and of the four types of heads, were turned over to AFGL for duplication as desired. It is believed that the work done in solving the battery-handling problem will make a substantial contribution to the success of future balloon operations at HAFB, including telescope flights, and it will permit experimenters to have batteries that are known to be satisfactory because the new equipment allows precise measurement of the capability of every single cell.

#### 8. SYSTEM IMPROVEMENTS

In its original configuration the 50-inch system included no means for telemetering scientific data. Instead data were recorded on board in both analog and digitized form, using recorders that had been flown extensively in work with the 24-inch system. There was some uneasiness about the continued reliability of this recording equipment because of the multiple recoveries, some of which were rugged. Also, gain settings had to be very carefully selected to be sure the dynamic range of all signals was adequately covered. About half way through the contract the dynamic range problem was solved by adding a commercially built signal processor that automatically adjusted the signal levels. Still later a new digital recorder, complete with digitizer, was procured by AFGL from Telemetry Systems Engineering. This equipment completely solved the data storage problem, and made the digitized data available in the proper format for easy input to AFGL computers.

At about the time the new recorder was scheduled for delivery the means of tracking flights was improved by adding a VOR system to the balloon-borne flight equipment. Two other facilities were also added as a part of the VOR installation, namely a VHF telemetering system for sending VOR information to the ground station, and a VHF

command capability on the ground. These supplemented the HF telemetering and command capability that had always been carried. Addition of the VHF transmitter and receiver in the balloon package made possible further improvements in the scientific experiment because spare command channels became available for use in controlling the experiment, and more importantly it became possible for the first time to telemeter scientific data to the ground in both analog and digitized form. In order to take advantage of this opportunity it was necessary to make a design change in the unit being provided by Telemetering Systems Engineering, and this was done. Adding the VOR, the VHF command, the VHF telemetering, and the new digital recorder, greatly improved the capability of the telescope system in that reliable on-board recording was assured along with a complete telemetered record. Incorporating the new items not only required a reshuffling of the space, and the associated rewiring of a part of the system, but it presented a heat-dissipation problem as well. To solve the latter it was necessary to add heat sinks outside the package, and then to provide a traveling cover that would keep them from being effective during ascent through the lower atmosphere where the temperature is cold and the effectiveness of the heat sinks is several times larger than it is at ceiling altitude.

Further changes in data handling are now possible because a PCM command and telemetering facility has recently been installed at HAFB. A companion installation of a PDP11/40 computer is also in progress, and this will further enhance the data processing that is possible at the launch site.

Throughout the life of the contract a considerable number of improvements were added that simplified and made more efficient the work that has to be done in the field. Although these were not spelled out as items to be studied, the changes were incorporated as a means of assisting the experimenters in getting the field work properly done. There was a continuous effort to design and construct test fixtures, black boxes, special circuitry, and hardware that



would simplify the preflight alignment with the result that time needed to prepare a flight was appreciably shortened and the certainty with which some of the alignment could be done was significantly improved. Providing such gadgets and techniques was considered an important part of helping the scientific people perform their work, and so too was the managing of liquid gases, supplying tools, helping troubleshoot experiment equipment, lending a hand when needed, and recording and writing up procedures found useful in preflight checkout work. Every experiment was somewhat different from the previous ones, so there was a continual need for making changes in the system, some of which required a substantial amount of planning and doing. Problems associated with the evolving system provided interesting challenges, such as making circuit modifications for rastering in a manner that allowed the spectrometer to always receive energy from the same spot on the field mirror, devising a better scheme for precisely locking the gimbal during checkout, rigging two instead of one alignment telescopes to make for a better alignment of the spectrometer, installing a larger lens in the acquisition tracker to permit acquiring dimmer targets, devising procedures to artificially simulate acquisition, or making a special IR target for checkout.

Several items were introduced at different times to improve the recovery operation. A very important contribution was the design and manufacture of a special platform for bringing back the payload after recovery. Retrieving the heavy, awkward payload with this vehicle was much easier than it had been early in the program when trucks were used. Another important recovery aid was a set of separate special packages for the various optical components that are removed in the field as a part of the recovery operation. Having properly sized and labeled containers both shortened the work of those making the recovery, and insured the safe return of delicate equipment. Except for a couple of flights, where recovery was near the launch site, the payload was always retrieved by a group of military person-

nel under the direction of a single, and highly knowledgeable, person at Holloman. His problems were made somewhat easier by providing his group with the special tools that were needed in partially dismantling the flight equipment, and by supplying a recovery manual that precisely stated what should be done and in what order. Use of this manual supplemented the full and careful preflight briefing that was always given to the particular crew that would make the recovery.

Most balloon flights at HAFB involve a fair amount of assembly out on the launch line, such as attaching the chutes to the payload, adding antennas and impact pads, doing protective taping, etc. Such was also true in early flights of the 50-inch system, but assembly type operations on the flight line were completely eliminated by the end of the contract period. This was accomplished by making special containers for the parachutes and release rigging, complete with casters wheels, that could be carried on the front of the telescope rack even though the parachutes were completely rigged, taped, and ready to go. Time required on the flight line was greatly reduced because the chutes and rigging could be quickly and easily lowered to the ground, and laid out in flight configuration without requiring extra personnel from the launch team or the use of forklifts to carry the heavy containers. Impact pads, flashing lights, antennas and such were also installed before moving out to the launch line. Engineering the assembly so that it could be finished long before flight time allowed the lengthy and exacting process to be accomplished in an unhurried way, and under circumstances of temperature and lighting that are appropriate to quality work.

#### 9. LIST ON CONTRIBUTORS

Alvin H. Howell  
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**10. RELATED CONTRACTS AND PUBLICATIONS**

**This contract was a follow-on of contract F19628-70-C-0256, but there are no other related contracts or publications.**